RATE OF DETERIORATION OF FIRE-KILLED TIMBER IN CALIFORNIA

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Forest Service

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CONTENTS

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INTRODUCTION

Forest fires kill an average of 131 million board-feet of merchantable timber each year in California.[2] Forest fires also destroy young trees and forage crops, and damage the watersheds. This circular, however, is concerned with losses in merchantable timber. The young trees killed by fire are a total loss, but much of the valuable material in the merchantable trees may be saved by prompt salvage operations. If not salvaged, these trees soon deteriorate beyond all use for lumber.

Prompt removal of the dead trees is also desirable to improve production from the land. If the dead trees are left, they harbor injurious insects and fungi, they constitute a serious fire hazard, and they hinder the establishment of new forest cover. Where forests are harvested under sustained yield management, merchantable timber in extensive fire-killed stands must be salvaged in order to maintain the allowable cut throughout the rotation.

Knowledge of the rate of loss from decay is needed in planning efficient salvage operations in fire-killed stands. The results of a study designed to supply such information are reported in this circular. The study was conducted from 1947 to 1949, at selected locations in the commercial forests of the mixed-conifer type in California.

Various investigations have been made of the deterioration of standing dead trees in both the United States and Canada. Since these studies have dealt mostly with trees killed by insects, the rate of deterioration reported does not necessarily apply in burned-over stands of timber. Insect-killed trees often stand alone or as small groups of dead trees in a green forest, and they may not deteriorate at the same rate as dead trees standing in an open, fully exposed burned area. Deterioration of fire-killed pulpwood stands in eastern Canada was studied by Skolko [3] in 1947. Earlier studies by the present writer

[1] The California Forest and Range Experiment Station is maintained by the Forest Service, U. S. Department of Agriculture, in cooperation with the University of California at Berkeley.

The study reported here was conducted under provisions of the Research and Marketing Act of 1946.

[2] Source of information: Forest Survey, California Forest and Range Experiment Station. The average loss reported is the most recent information available. It is based chiefly on the period 1943–48, inclusive.

[3] Skolko, A. J. deterioration of fire-killed pulpwood stands in eastern canada. Forestry Chron. 23: 128–144, illus. 1947.

and others [4,5,6,7] provided information on the deterioration of fire-killed Douglas-fir in western Oregon and Washington. The study reported here is the first made of the deterioration of fire-killed trees in California.

METHOD OF STUDY

The rate of decay was determined from dissected trees (fig. 1) that had been dead for different lengths of time. Detailed notes were taken on the extent of deterioration in each study tree in burns of different ages. In most places, the trees were felled for the study and cut into 16.3-foot sections. In a few areas the trees were cut primarily for logging in salvage operations, and the logs usually were 16 feet in length plus trim allowance. Data were taken after the trees had been bucked into logs, and detailed examinations were made at the stump and at each bucking cut or break. In the logging areas, examinations of the tops above the utilized portion of the bole were made by chopping into the tops at desired intervals. Some of the logs were checked for extent of deterioration as they were sawn into lumber.

Study areas were selected primarily for the age of the burn but also for general location in regard to elevation and exposure. Nineteen study areas were selected in 16 different burns, from 0 to 17 years old, in the Sierra Nevada and in the Coast Ranges of northwestern California (fig. 2). Individual study trees were selected, first, to be certain that the tree had been killed outright at the time of the fire, and second, to obtain a wide range of tree sizes. A total of 578 trees were used in the study (table 1): 523 were dissected to determine the rate of decay and 55 were used in a supplemental study of cambium moisture to help in determining the conditions influencing rates of decay.

Trees killed outright by the fire were used in the study because the exact time of death was known. Where crown fires or very hot ground fires occur, most trees are killed outright. In most forest fires in California, however, many trees not killed outright are injured by fire. Those most severely injured are usually attacked by bark beetles and die within the next year. Some are killed the second or third year by bark beetle attacks stimulated by the fire injury or by proximity to heavily infested surrounding trees. Thus, the average extent of deterioration determined by this study can be applied to trees not killed outright only if the time of their death is definitely known.

Five species of conifers were included in the study: Ponderosa pine (*Pinus ponderosa* Laws.), Jeffrey pine (*P. jeffreyi* Grev. & Balf.), sugar pine (*P. lambertiana* Dougl.), Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), and white fir (*Abies concolor* (Gord. &

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[4] Beal, J. A., Kimmey, J. W., and Rapraeger, E. F. deterioration of fire-killed douglas-fir. Timberman 37 (2): 12–17, illus. 1935.

[5] Furniss, R. L. salvage on tillamook burn as affected by insect activity. Timberman 39 (2): 11–13, 30, 32, illus. 1937.

[6] Kimmey, J. W. and Furniss, R. L. deterioration of fire-killed douglas-fir. U. S. Dept. Agr. Tech. Bul. 851, 61 pp., illus. 1943.

[7] Knapp, J. B. fire-killed douglas-fir: a study of its rate of deterioration, usability, and strength. U. S. Dept. Agr. Forest Serv. Bul. 112, 18 pp., illus. 1912.

FIGURE 1.—Methods of tree dissection for study of deterioration in fire-killed timber: *A*, Felling fire-killed ponderosa pine tree; *B*, bucking pine into 16.3-foot log; *C*, dissected ponderosa pine in a 3-year-old burn, showing cut ends of each log; and *D*, measuring and taking notes on deterioration in dissected sugar pine in a 4-year-old burn.

Glend.) Lindl.). Lumbermen seldom differentiate between ponderosa and Jeffrey pines. Because the two species have many similarities, both in physical characteristics and rate of decay, the data for ponderosa and Jeffrey pines were combined.

Field data were taken so that volumes of sapwood and heartwood and the extent and degree of deterioration in each could be determined for each log, the stump, and the top. Board-foot volumes were determined from an 18-inch stump to an 8-inch top diameter inside the bark. The Scribner Decimal C scale was used, and the logs were scaled in accordance with the National Forest Scaling Handbook. Cubic volumes were determined for each log, for the top from the 8-inch diameter to the tip, and for the stump. The stump was considered a cylinder with a diameter equal to that of the top of the stump inside the bark.

FIGURE 2.—Location of burns where deterioration studies were conducted and the commercial range of the conifer species studied.

THE DETERIORATION PROCESS

Practically no sound material that is ordinarily merchantable for lumber in green trees is consumed by a forest fire. Soon after the trees are killed by the fire, however, deterioration of the main bole begins and continues until no sound wood remains.

Deterioration in fire-killed trees has been defined [8] as the physical changes that take place in a tree following death by fire. In this report we are concerned primarily with those changes in character and color of the wood of the main bole that affect its merchantable value.

[8] See footnote 6, p. 2.

Two phases of deterioration may be recognized, that is, limited and general. The term "limited deterioration" applies to changes from the original character of the wood that limit the value of the wood for lumber, whereas "general deterioration" applies to changes that make the wood undesirable for lumber, even of low grade.

TABLE 1.—*Study areas and number of trees, by species, for cambium-moisture and rate-of-deterioration studies in California, 1947–49*

CAMBIUM-MOISTURE STUDY

Name of burn	Location [1]	Age of burn	Year studied	Number of trees by species [2]					
				P. P.	J. P.	S. P.	D. F.	W. F.	Total
		Years							
French Creek	E. S.	0	1947		9				9
Sandy Camp	E. S.	0	1947	3	6			4	13
Smith Creek	Inter.	1	1947			6	4	4	14
Clear Creek	W. S.	1	1947	10		5	4		19
Total				13	15	11	8	8	55

RATE-OF-DETERIORATION STUDY

Name of burn	Location [1]	Age of burn	Year studied	P. P.	J. P.	S. P.	D. F.	W. F.	Total
Smith Creek	Inter.	1	1947	2	2	16	16	16	52
Johnson Grade	Inter.	2	1948					13	13
Spanish Creek	W. S.	2	1948	8		12	21	11	52
Clear Creek	W. S.	2	1948	19		20	24		63
Boca	E. S.	2	1949	18	20	16			54
Schuyler Ranch	C. R.	2	1949	4		1	4		9
Five Mile	W. S.	3	1949	22		16			38
Spanish Creek	W. S.	3	1949	15		10	3	11	39
Damons Butte Rd	E. S.	3	1948	16	21				37
Kimshew	W. S.	3	1948	5		7		8	20
Boardman Ridge	C. R.	4	1948	23		12	7		42
Crestview	E. S.	5	1949		24				24
Shannon Butte	C. R.	5	1949	14			6		20
Black Rock	W. S.	6	1949	11		13		12	36
Mooreville Ridge	W. S.	17	1948	1		11	9	3	24
Total				158	67	134	90	74	523

[1] E. S.—Eastside Sierra; W. S.—Westside Sierra; Inter.—Conditions intermediate between Eastside and Westside Sierra; C. R.—Coast Range Mountains.

[2] P. P.—Ponderosa pine; J. P.—Jeffrey pine; S. P.—Sugar pine; D. F.—Douglas-fir; W. F.—White fir.

The principal agents causing deterioration are fungi and insects. Weather, a third and minor agent, may at times become indirectly of major importance. Fungi and insects usually are closely associated in the deterioration process and at times have a symbiotic relationship. Often the fungi are introduced by insects or enter independently through insect holes in the bark; some insects introduce specific fungi upon which they depend for food. In any event, the initial attack by the two agents is usually considered to be practically simultaneous and they work together, at generally similar rates.

Fungi Causing Deterioration

In the process of deterioration of fire-killed trees, a continuing succession of fungi attack the trees. The relative predominance of the various types and species of fungi changes from year to year until deterioration is complete. The relative order of importance of the various decay fungi and stains found in this study is given in table 2, separately for the sapwood and heartwood for the tree species studied.

In some tree species, especially the pines, the first sign of deterioration usually is a staining of the outer sapwood. This so-called blue stain (also referred to as sap stain) ordinarily becomes evident within the first year after the fire. Many fungi cause stain in fire-killed trees, producing discoloration of varying shades of blue, gray, brown, and black.

The staining fungi live primarily on the contents of sapwood cells and do not materially weaken the wood they invade. This fact has become rather generally recognized, and in recent years the old prejudice against blue-stained wood has largely disappeared. Although blue-stained wood is ordinarily reduced in value, or degraded, because of its color, it is, if not otherwise weakened, as suitable as unstained wood for uses where the discoloration is not objectionable.

In fire-killed trees, conditions favorable for the development of the staining fungi are also favorable for the development of decay fungi. Although both types of fungi may be introduced into fire-killed trees simultaneously, the wood rotters develop at a comparatively slower rate. The first signs of wood decay usually become evident in the second year following the fire.

The decay fungi chiefly concerned in the deterioration of fire-killed trees enter after the fire and start just under the bark. They are often termed scavenger fungi and are of two general types: (1) Those that decay primarily the sapwood; and (2) those capable of decaying both sapwood and heartwood. The scavenger fungi soon penetrate the entire sapwood and those of the second group then continue, at a slower rate, into the heartwood. Heartrot fungi that may already be present in the trees at the time of the fire usually are relatively inactive and play little part in the deterioration process.

In the incipient or early stage of decay, the mycelia of the decay fungi penetrate the wood for a short distance beyond the distinctly, or typically decayed wood. This advance zone of incipient decay is usually marked by some discoloration and softening of the wood. The wood so invaded is often materially weakened, and if lumber manufactured from it is not thoroughly dried, the fungi may continue their disintegrating action. Therefore, in this study, wood containing visible incipient decay was considered a loss also.

Three species of scavenger fungi cause most of the decay in fire-killed trees: Red-belt fungus (*Fomes pinicola*), pouch fungus (*Polyporus volvatus*), and purple fungus (*P. abietinus*).

The red-belt fungus is a prolific destroyer of both sapwood and heartwood of fire-killed trees of all the species studied;[9] it causes

[9] *Fomes pinicola*, besides being the most important decayer of dead wood throughout the northern hemisphere, causes much decay of heartwood in living Sitka spruce and western hemlock in Alaska.

TABLE 2.—*Decay fungi and types of stains found in fire-killed timber in California, in 16 different burns, from 0 to 17 years old, listed in order of predominance*[1] *in sapwood and in heartwood for each tree species studied*

White fir		Douglas-fir		Sugar pine		Ponderosa and Jeffrey pines	
Sapwood	Heartwood	Sapwood	Heartwood	Sapwood	Heartwood	Sapwood	Heartwood
Fomes pinicola (Fr.) Cke.	*Fomes pinicola*	*Fomes pinicola*	*Fomes pinicola*	Blue stain	*Fomes pinicola*	Blue stain	*Fomes pinicola.*
Polyporus volvatus Pk.	*Polyporus abietinus*	*Polyporus abietinus*	*Fomes officinalis*	*Fomes pinicola*	*Fomes officinalis*	*Fomes pinicola*	Pink stain.
Polyporus abietinus Fr.	*Pholiota adiposa*	*Polyporus volvatus*	Pink stain	*Polyporus volvatus*	*Polyporus anceps*	*Polyporus volvatus*	Yellow stain.
Pholiota adiposa (Fr.) Kummer.	*Fomes officinalis*	*Fomes officinalis*	*Poria albipellucida* Baxter.	*Polyporus abietinus*	Orange stain	*Polyporus abietinus*	
Fomes officinalis (Fr.) Faull.	*Fomes annosus*	*Fomes applanatus* (S. F. Gray) Gill.		*Polyporus anceps* Pk.	*Trametes serialis*	*Polyporus anceps*	
Fomes annosus (Fr.) Cke.	*Armillaria mellea* (Fr.) Kummer.	Blue stain		*Lenzites saepiaria* Fr.		*Lenzites saepiaria*	
Blue stain				*Trametes serialis* Fr.		Brown stain	
				Poria cocos Wolf		*Fomes annosus*	
						Unidentified fungi	

[1] The order of predominance, listed here, applies to burns of the ages studied. In older burns the order of predominance and probably the list of agents involved would be different.

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the greatest proportion of decay in the deterioration process. The sporophores, or conks, of this fungus are the most commonly found conks on dead conifers in the California forests, and are familiar to all woodsmen. The mature conks range in size from a few inches to more than a foot in diameter. They are perennial, adding a new pore-layer each year, and the shapes range from shelflike to hoof-shaped. The layers are indicated by the zoned structure of the top, which is smooth and gray to black. The lower surface is white to light cream and contains numerous small, regular, round pores. During the growing season the margins are nearly white, but later they usually become shiny red—hence, the name red-belt. The decay caused by this fungus in fire-killed timber first appears in the sapwood, in long streaks of pale-yellow to light-brown stain, during the first or second year after the fire. The typical or advanced stage of this decay is a brown, crumbly rot of charcoal consistency, which breaks up into cubical pieces by the formation of shrinkage cracks, in which thin layers of white mycelium often develop.

The pouch fungus, which causes decay only in the sapwood, is second in importance in the decay of fire-killed timber. Protruding from insect burrows in the bark, the young annual sporophores appear the second and third years after a fire. The young sporophores are small, flattened-globose, and reddish brown. When mature the sporophores are tan to white and may reach a size of 1 to 1.5 inches in diameter. The brown, flat, minutely pored fruiting surface is completely covered by a leathery membrane, continuous with the upper surface except for a small, irregular opening, which appears in the membrane at maturity. Decay produced by this fungus is typically cream to light tan, varying little from the normal color of the sapwood. Even in the most advanced stages encountered, the pouch fungus only softens the wood. Though firm and without pockets, the decayed wood becomes brash and has a somewhat cheesy consistency, breaking more easily and more squarely across the grain than sound sapwood. Within 2 years after fire, the decay may penetrate to the entire depth of the sapwood, but other fungi attack the same wood and, by causing a more complete breakdown of the wood, soon obscure the deterioration caused by the pouch fungus.

The purple fungus, which is confined to the sapwood in all species studied except white fir, ranks third in importance as a cause of decay in fire-killed trees in California. After penetrating the sapwood of white fir, this fungus often works on into the heartwood. The sporophores are small, thin, and bracket-shaped, usually 1 to 3 inches across at maturity. They are annual and are usually numerous and often crowded together, one above the other, along the bark crevices of the fire-killed trees. The upper surface is hairy, zoned, and white to gray, becoming darker with age. The name purple fungus is derived from the purple lower surface, which contains numerous regularly or irregularly shaped pores. On the surface of a log the decay first appears as water-soaked areas under the bark, and in sections of the wood as yellowish stain during the first or second year after the fire. The typical decay is a white rot, which in the late stage contains shallow, long pockets that give the wood a fine-honeycomb appearance. The small pockets are lined with a thin layer of white fibers, which

appear as white flecks in the decayed wood. In the final stage, the pockets become empty and the decayed wood becomes spongy and very light in weight, and it easily separates into layers along the annual rings.

A number of other decay fungi, including some of those common in the heartwood of living trees, individually play a minor role in the deterioration process. Collectively these fungi constitute a significant loss factor, especially in older burns. At times a less-important fungus was found to cause serious decay in individual trees.

Also, several minor stains were occasionally encountered in the heartwood. These stains, which were pink, yellow, or orange, are of undetermined origin, as was a brown stain found rarely in the sapwood of Jeffrey pine. Although some may be due to fungi, culturing indicated that these stains are not produced by fungi that cause decay. Some may be caused by *Fusarium* species or by mold fungi. Most of the heartwood stains usually fade when the wood is dried and exposed to light, but the brown stain of Jeffrey pine sapwood persists even after thorough drying and long periods of exposure.

Other Agents Causing Deterioration

Of the insects that play a part in the deterioration of wood of fire-killed trees, some introduce fungi, and others make bark openings for fungus entry. Bark beetles and other insects penetrate the bark and inhabit the phloem region of the inner bark and the cambial region of the wood under the bark. Later, wood borers enter the sapwood and make galleries. Few sapwood borers are important in the salvage problem, for they seldom become abundant enough to cause cull of the wood before fungi render it useless for lumber. Galleries in combination with stains at times cause degrade in the sapwood. Some borers later bore on into the heartwood, where their galleries, even without accompanying decay, are sufficient to cause degrade.

The weather may have either a direct or an indirect effect on deterioration of fire-killed trees. Ordinarily, little deterioration is attributable directly to weathering. Checking occurs in the outer sapwood after the sapwood becomes dry, but it occurs usually long after fungi and insects have deteriorated the wood beyond use for lumber. Checking is most severe in tree tops, especially in stands on south slopes or other dry sites at high elevations. In such situations, where attack by fungi and insects has been retarded by lack of moisture, some checks may extend deeper than the general deterioration. This deep checking, however, occurs mostly in the upper parts of the bole above the merchantable diameter limit. Part of the bark had been burned off a few of the trees studied. In some of these trees a small amount of deterioration resulted from checks in the exposed areas of sapwood.

The weather has a more important, though indirect, effect by influencing growth conditions for the other agents that cause deterioration. Weather conditions may limit the species and number of fungi and insects, may retard their progress, or may provide conditions so favorable that deterioration is accelerated beyond the average rate.

RATE OF DECAY

Immediately after the fire, killed timber contains approximately the same merchantable volume that it did just before the fire. During the first 12 months after the fire, fungi attack the sapwood. In most burns they cause little loss of volume, or cull, if the timber is salvaged before the end of the first year, though often some degrade will be encountered toward the end of that year. This degrade is caused largely by blue stain in the sapwood. On burns at the lower elevations, and especially on southern exposures, the amount of degrade will be considerably more than average by the end of the first year.

By the end of the second year, the percentage of cull will be approximately the same as the percentage of sapwood in the trees. Some trees will have cull material in the outer heartwood; other trees will still contain some salvable sapwood. Thus the percentage of loss at the end of the second year will depend largely upon the thickness of sapwood and the size of trees. The thickness of sapwood varies considerably between tree species, but is rather uniform within species.

Practically all of the sapwood will be culled by the end of the third year and, in addition, the outer heartwood in some trees will contain appreciable deterioration.

After the third year the rate of volume loss through decay is somewhat retarded and starting with the fourth year is fairly uniform from year to year. The rate of loss varies with tree species, but the size of the trees also influences the rate of loss in the heartwood. Since the rate of volume loss in the heartwood of an individual tree is fairly constant, the rate of penetration must accelerate from year to year. A greater penetration is necessary each succeeding year to cause equal volumes of cull.

In this study the average rate of loss was determined for each of the tree species studied, ponderosa and Jeffrey pines being considered together. Since the extent of volume lost at any time after the fire varies considerably with the size of tree, the average extent of deterioration at yearly intervals was determined for trees of different diameters.

Rate of deterioration was determined in both cubic- and board-foot terms. The actual extent of deterioration is best shown as a percentage of the cubic-foot volume, because only actual volumes of deteriorated wood are deducted from the gross cubic-foot volume. In board-foot computations it is necessary to deduct some sound material that is interspersed with deteriorated wood; therefore, the percentage of the board-foot volume that is deteriorated is greater than the cubic-foot volume deteriorated.

Extent of cull also was determined for each species. Cull is the percentage of the gross volume that is deducted in scaling because of deterioration of the wood. Pine logs with more than two-thirds of their gross board-foot volume deducted are considered 100 percent cull, and Douglas-fir or white fir logs are considered 100 percent cull when more than one-half of their gross board-foot volume is deducted. For this reason the percentage of the gross board-foot volume that is culled is usually more than the percentage deteriorated.

White Fir

White fir trees killed by fire deteriorate faster, in both the sapwood and the heartwood, than any of the other species studied. General deterioration in white fir trees by the end of the first year averaged 10 to 20 percent of the gross cubic-foot volume, depending upon the size of trees (fig. 3, *A*). This deterioration was principally the incipient stage of decay in the outer sapwood. There is very little blue stain in this species.

By the end of the second year, decay fungi penetrated most of the comparatively thick sapwood and in places extended into the outer heartwood. On the average, general deterioration affected approximately one-half of the gross cubic-foot volume (fig. 3, *A*), and resulted in cull of about 70 percent of the gross board-foot volume (fig. 3, *C*). Therefore, under average conditions it is not economically feasible to log fire-killed white fir after the second year, except for some of the lower logs from the larger trees. In some high-elevation burns, however, especially on northerly exposures, a considerable amount of white fir may be salvaged in the third year, and some even in the fourth year; in exceptional cases, basal logs from extra-large trees may be salvable in such burns after the fourth year.

Douglas-Fir

The heartwood of fire-killed Douglas-fir deteriorates more slowly than that of any of the other species studied. Although the sapwood does not deteriorate slowly, it is slightly thinner than the sapwood of the other species. The rate of deterioration for fire-killed Douglas-fir in the California forests is shown in figure 4.

The rate of decay in the heartwood was found to be practically the same in the California trees as the rate reported in 1943 for fire-killed Douglas-fir in western Oregon and Washington.[10] The more detailed report of this earlier study is generally applicable to the species in California. Although the sapwood of Douglas-fir is somewhat thicker in California, it becomes generally deteriorated by the end of the third year, as in the Pacific Northwest. Deterioration in the sapwood of fire-killed Douglas-fir in California differed from that in the Northwest in two ways; in California very little blue stain occurred, and incipient decay was more prevalent by the end of the first year. Consequently, limited deterioration was less in the sapwood of the California trees.

Large trees of fire-killed Douglas-fir will contain salvable material for many years. In the oldest burn of the California studies, the heartwood of Douglas-fir trees dead for 17 years was less than 35 percent decayed. These trees averaged 41 inches in diameter breast high. This rate of decay is similar to that found in trees of similar size in the Pacific Northwest.

Sugar Pine

Fire-killed sugar pine was the most durable of the three pines studied, and second to Douglas-fir in durability. Sugar pine sapwood, which makes up 25 to 70 percent of the gross cubic-foot volume, de-

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[10] See footnote 6, p. 2.

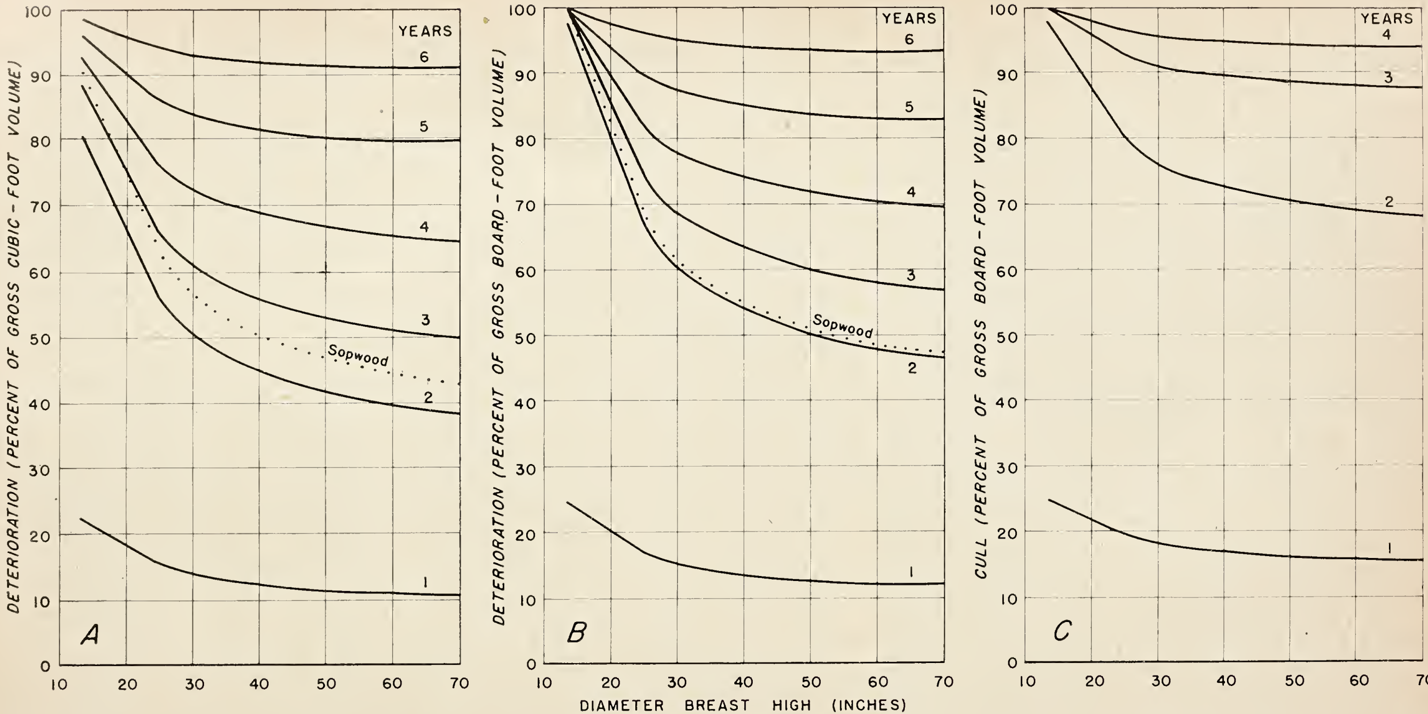

FIGURE 3.—Deterioration of 74 fire-killed white firs in relation to tree diameter. Average percent of (*A*) gross cubic-foot volume that was sapwood and of volume that was deteriorated after each of 6 years, (*B*) gross board-foot volume that was sapwood and of volume that was deteriorated after each of 6 years, and (*C*) gross board-foot volume culled because of deterioration each year for 4 years after the fire.

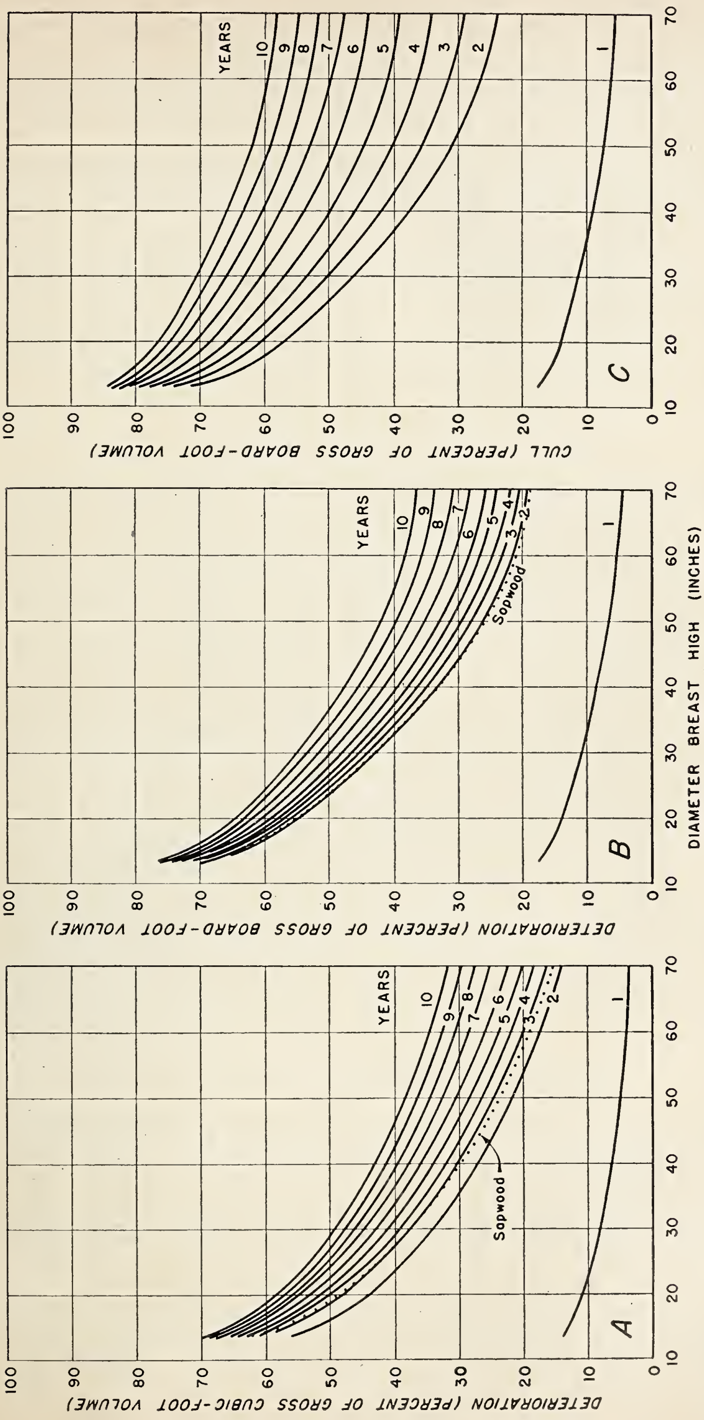

FIGURE 4.—Deterioration of 90 fire-killed Douglas-firs in relation to tree diameter. Average percent, each year for 10 years after the fire, of (*A*) gross cubic-foot volume that was sapwood and of volume that was deteriorated, (*B*) gross board-foot volume that was sapwood and of volume that was deteriorated, and (*C*) gross board-foot volume culled because of deterioration.

pending on tree size (fig. 5, *A*), is very susceptible to blue stain. Ordinarily, more than one-half of the cubic-foot volume (fig. 5, *A*) and more than three-fourths of the board-foot volume of the sapwood (fig. 5, *B*) was blue stained by the end of the first year after the fire. However, by that time only about 2 percent of the sapwood contained general deterioration caused by decay fungi.

By the end of the second year practically all of the sapwood was blue stained and about three-fourths was generally deteriorated by fungi and insects.

All of the sapwood was generally deteriorated by the end of the third year and some decay was found in the outer heartwood. However, the heartwood is very durable, and in large trees salvable material may be found for many years (fig. 5, *C*). In the oldest burn included in this study, large sugar pines contained appreciable amounts of sound heartwood 17 years after being killed by fire.

Ponderosa and Jeffrey Pines

The extremely thick sapwood of ponderosa and Jeffrey pines, which ordinarily constitutes from 50 to 75 percent of their cubic-foot volume (fig. 6, *A*), is more resistant to general deterioration than the sapwood of any of the other trees studied. On the average, at the end of the first year after the fire the sapwood showed practically no general deterioration from decay fungi, but about one-fourth of the cubic volume of the sapwood contained limited deterioration, due principally to blue stain.

General deterioration of the sapwood usually became evident in the second year, and by the end of that year about one-half of the cubic volume of the sapwood contained incipient decay. Even then, very little decay was evident in some trees. By this time, however, most of the sapwood had become blue stained.

Appreciable deterioration in the heartwood of ponderosa or Jeffrey pines usually was not found until the third year after the fire. At the end of the third year, the average percentage of deterioration, including that in both the sapwood and heartwood, was still slightly less than the average cubic-foot volume of the sapwood (fig. 6, *A*). For all practical purposes, therefore, the sapwood of these pines is decayed approximately 3 years after the fire, and only very large trees contain enough sound board-foot volume to be salvaged economically (fig. 6, *C*).

Breakup of Fire-Killed Stands

During the first 2 years after a fire there is little noticeable change in the general appearance of fire-killed timber stands. A few small branches and twigs drop in heavy storms, the dead foliage falls, and some loose bark is evident in the tops of small trees of the thinner barked species. Woodpeckers peck small holes, or chip off patches of outer bark from small trees, or from larger trees that have died since the fire.

In the third year, evidence that the stand is breaking up becomes plain. Some of the smaller trees, up to 10 or 12 inches in diameter, of the species with thick sapwood break off at various heights from

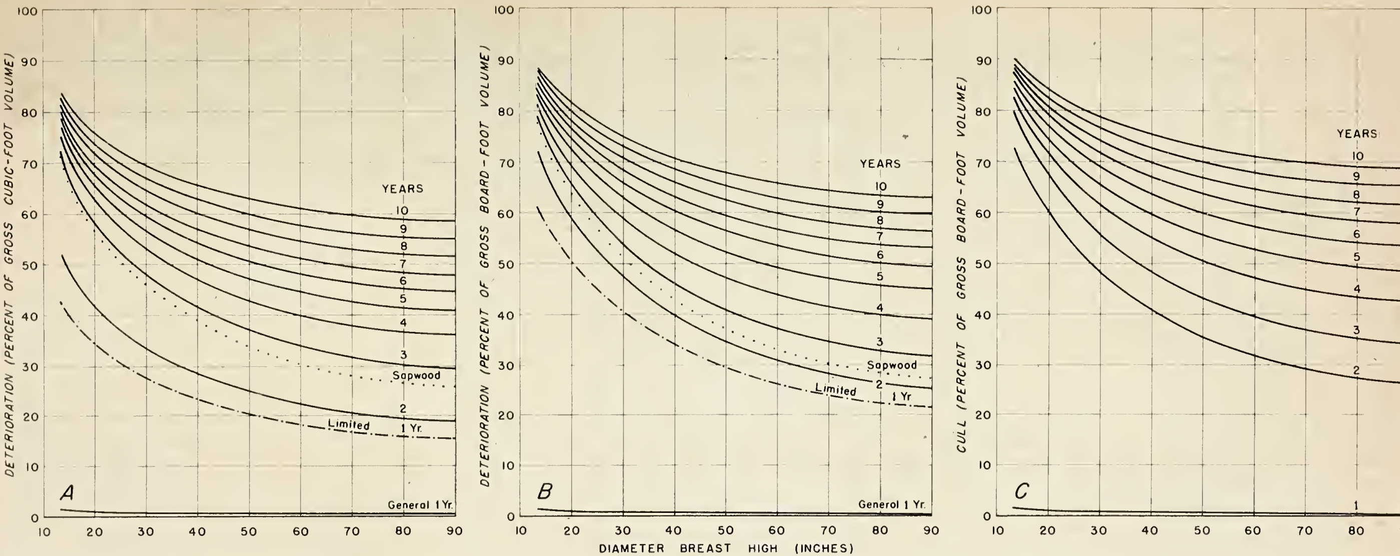

FIGURE 5.—Deterioration of 134 fire-killed sugar pines in relation to tree diameter. Average percent, each year for 10 years after the fire, of (*A*) gross cubic-foot volume that was sapwood and of volume that was deteriorated, (*B*) gross board-foot volume that was sapwood and of volume that was deteriorated, and (*C*) gross board-foot volume culled because of deterioration.

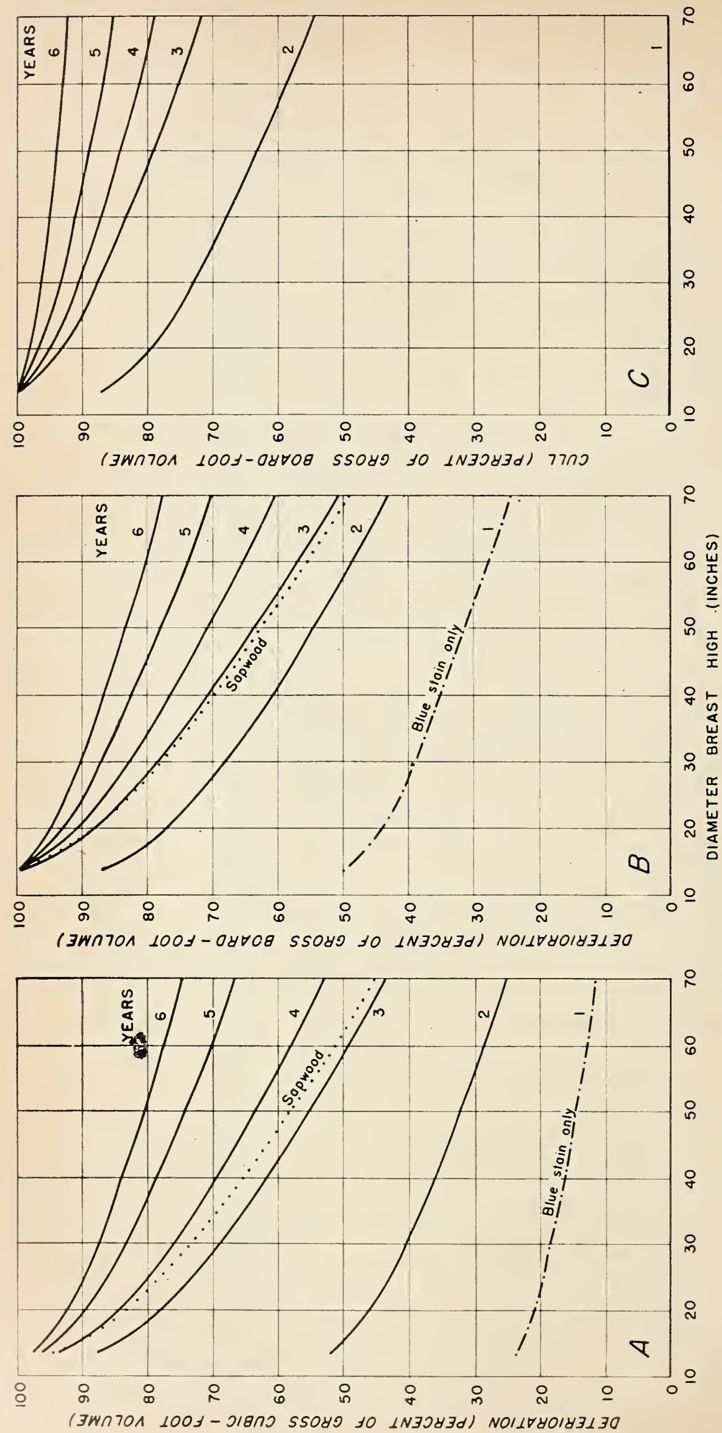

FIGURE 6.—Deterioration of 225 fire-killed ponderosa and Jeffrey pines in relation to tree diameter. Average percent, each year for 6 years after the fire, of (*A*) gross cubic-foot volume that was sapwood and of volume that was deteriorated, (*B*) gross board-foot volume that was sapwood and of volume that was deteriorated, and (*C*) gross board-foot volume culled because of deterioration.

the ground. The outer ends of smaller branches break and fall, the thin bark becomes loose on small trees and in the tops of larger trees, and some bark drops off.

In the fourth and fifth years, many ponderosa or Jeffrey pines and white firs of small size break off at ground level or up to 50 or more feet above the ground. Even some of the larger trees of these species and smaller trees of sugar pine and Douglas-fir will break off by the fifth year. A considerable amount of bark drops from the bole throughout and just below the base of the crown. By the end of the fifth year, only a few of the larger Douglas-fir trees appear unchanged since the fire.

After the fifth year the general breakup continues until only scattered barkless snags and stubs remain. The ponderosa pine and white fir trees are the first to drop from the dead stand. Since the amount and durability of the heartwood determine a tree's resistance to breaking and dropping, the larger sugar pines and Douglas-firs outlast the other trees. The last remnants of a stand are short stubs of the largest Douglas-firs, unless the stand includes a more decay-resistant tree species, such as incense-cedar (*Libocedrus decurrens* Torr.).

Some exceptions to this general pattern of breakup occur. At high elevations and on dry sites, the decay in the upper bole is arrested by drying. Drying is particularly prevalent in the thin-barked species and smaller trees. In such cases, fungi are active only near the base of the tree, where moisture from the ground is sufficient to permit decay. The dead trees then rot off at or near the ground and drop full length, rather than piece by piece from the top as on lower or wetter sites. Thus, where lack of moisture limits decay, the larger and thicker barked trees may be among the first to drop, and the smaller, thin-barked trees may be the surviving remnants of the stand.

CONDITIONS INFLUENCING RATE OF DECAY

Several factors besides tree species, tree size, and percent of sapwood influence the rate of decay. Among these others, environmental factors, such as climate, elevation, and aspect, probably have the greatest effect. And there is evidence that the intensity of the fire and rate of tree growth also affect the rate at which fire-killed timber deteriorates.

Environmental Factors

The progress of decay fungi and insects in causing deterioration of fire-killed trees is governed principally by moisture and temperature in the wood. Although the fungi and insects tolerate wide ranges of temperature and moisture, the optimum ranges are somewhat narrower and the duration of optimum conditions may be limited in some localities.

Wet wood will support fungus growth until all or most of the oxygen is displaced by water; however, the wood in a standing killed tree probably absorbs very little moisture in the first few years after death even where the climate is wet; where the climate is dry, moisture may be lost quite rapidly and may never be regained. The rate of drying is affected by wind velocity and temperature as well as humidity. Temperature, which is increased under fire-blackened

bark, probably affects vaporization of the normal moisture in the wood. The lower moisture limit for optimum fungus development is about 27 percent, and fungus growth is arrested when the moisture content falls to near 20 percent. At high elevations and on the eastern slopes of the Sierra Nevada, deterioration caused by fungi and insects is considerably retarded, and at some localities completely arrested except at the base of the tree where ground moisture is available. This complete arrestment is undoubtedly due to the drying of the wood, but the retarding effect is probably due largely to temperature conditions.

Temperature in the wood of fire-killed trees probably never rises too high for the growth and development of fungi and insects; some scavenger fungi will continue to grow at temperatures up to 95° F. or more. On the other hand, the minimum temperature at which these fungi will grow is probably about 41° F. It is probable that temperatures inside trees at the higher elevations rarely reach the optimum for the common scavenger fungi, and for several months of the year the temperatures are too low for appreciable fungus growth.

The principal deterioration on dry, high-elevation sites is the checking of the dried wood in the tree boles. So-called season or weather checks may extend to the pith even in fairly large trees before they eventually rot off at the base and topple to the ground. Even after falling, sections of the bole not in direct contact with the ground may decay very slowly.

Within a single burned area some difference in rate of deterioration may be found on different aspects. For instance, if the site is humid, the rate of deterioration may be greater on southerly slopes than on northerly slopes. Variation in the rate of deterioration may even be found in different parts of a tree. When the wood in fire-killed trees is excessively wet, deterioration will be faster on the south side of the trees, and later, after the trees dry somewhat, deterioraion will be faster on the north side. Also, deterioration is faster in the upper parts of wet trees and in the lower parts of dry trees.

Severity of Burning

Early in the study it was noted in one burn that the rate of deterioration was slower in trees that had been burned so severely that all of the foliage had been consumed, as compared with trees that still retained their dead foliage. The sapwood of the severely burned trees was wetter, and staining was retarded.

A supplemental investigation was made in that burn and two other burns to determine if the degree of burning was a good indicator of rate of deterioration. A total of 185 samples of phloem and outer sapwood were collected from 55 trees (representing all species studied) in the 3 burns. Moisture determinations showed that trees without dead foliage were wetter than trees with attached dead foliage. However, the rate of staining and other deterioration was retarded in wet trees only on the wetter sites, whereas on the drier sites deterioration was accelerated in the the wet trees. These results showed that a single factor may not always have the same effect upon the rate of deterioration.

Rate of Tree Growth

Studies in the Pacific Northwest[11] have shown that fast-grown heartwood of fire-killed Douglas-fir with wide growth rings deteriorates faster than slow-grown heartwood with narrow growth rings. General observations showed that this applies also in California. The heartwood of the other tree species studied in California showed a similar tendency although the differences were not as great. In most trees the rate of growth is retarded with age, so that ordinarily old trees contain narrow growth rings in the outer heartwood. Therefore, the outer heartwood of old trees killed by fire generally is more resistant to deterioration than the outer heartwood of younger trees. This was especially noticeable in Douglas-fir and sugar pine. Other things being equal, the older a tree the slower will its heartwood deteriorate after the tree is killed by fire.

SALVAGE PROBLEMS

Many factors must be considered in planning the salvage of fire-killed timber. One of the important considerations is the rate of deterioration shown by this study. But timber owners and operators will sometimes find other factors equally important to the job—for example, the economics of salvage, including the values and costs in logging and milling fire-killed timber; or their plans for future development of the burned area and nearby timber.

Deterioration as a Factor in Salvage

Progressive deterioration in dead trees requires immediate or early salvage operations to recover a maximum of merchantable material from fire-killed timber. The period of practical salvability is largely dictated by the rate of deterioration. Timing of salvage operations will depend on which tree species dominate the stand. Salvage in stands predominately white fir should be completed within 1 to 2 years after the fire if appreciable sound wood is to be recovered. Some ponderosa and Jeffrey pines will yield 50 percent or more sound wood up to 3 years after the fire. Large sugar pines or Douglas-firs, in contrast, may remain mostly sound for 5 years or more. Logging and sawmill operators must remember, however, that the first and most rapid deterioration occurs in the sapwood of the fire-killed trees, and that the best grades of lumber are derived from this part of the tree. Blue stain alone causes only limited deterioration in the sapwood, so that the principal loss in pine in the first year or two is from lumber degrade rather than from culled material. As deterioration advances in the heartwood toward the center of the bole, the percentage of clear lumber that may be manufactured from the remaining sound core becomes progressively smaller.

Furthermore, the depth of decay at times is not uniform at all heights in a tree. Instead, decay may develop in patches or pockets. This is especially true in species with thick sapwood, such as white fir and ponderosa and Jeffrey pines. Because of the pockets, the volume of cull in logs often exceeds the volume actually deteriorated.

[11] See footnote 6, p. 2.

Most lumber mill operators, therefore, will be more interested in the progression of cull in board-feet (curves marked *C* in figures 3 to 6) than in the rate of deterioration.

When decay develops unevenly, the extent of cull is difficult to judge and scale accurately in the log, particularly in long logs. It is even harder to judge after the logs have soaked in a mill pond; some decay may not be seen until the log is cut open by the headsaw. Early stages of decay are especially troublesome and may not show up until the lumber has been seasoned and surfaced. Similar difficulty may be experienced in manufacturing lumber from thin-barked trees logged where weathering is the principal cause of deterioration: fine hair-checks may not become apparent until the boards go through the planer. Thus, the percent of cull may not be as important as the effects of cull on sawmill efficiency and lumber quality.

As general deterioration progresses, the amount of material that must be left in the woods increases. The smaller trees, which consist largely of sapwood, soon become unmerchantable. Then the upper part of the larger trees, with a larger share of sapwood and with heartwood that usually deteriorates more rapidly than the heartwood lower in the tree, becomes cull and must be left in the woods. After the sapwood is weakened by decay, breakage in felling increases, causing additional cull of sound material. As time passes the amount of material that must be culled when the salvaged logs are being cut into lumber also increases. This cull material hinders mill operation, increases operating costs, and reduces profits. The operators of most small mills find that the cost of processing salvaged fire-killed logs is prohibitive unless they can be interspersed with some green logs.

Other Considerations in Salvage Operations

Despite the need for timely operations, economic considerations may be of greatest importance in planning the salvage of fire-killed timber. Practically all salvage projects require extra expense because the cost of logging and lumber manufacturing is greater for dead timber than for green timber. The value of the killed timber and the costs of logging it must be determined early in the planning. Often physical elements are of primary concern. Such things as accessibility of the dead timber; size and character of the burn; size and species of trees killed; and the volume, by log grades, that may be salvaged can be critical elements of salvage planning. The operator's decision may be affected by whether he owns the timber or is buying it, whether he is only logging or milling, or both. The size and efficiency of his operations and equipment must be considered. The state of the log or lumber market makes a great difference in the salvability of dead timber containing limited deterioration in the sapwood. If there is a ready market for stained or for low-grade lumber, and if the operator has a large, efficient sawmill, he may profitably salvage fire-killed material from his own timber holdings when other operators under different circumstances could not make a profit.

A number of other considerations may enter into the salvage plans. If an owner of fire-killed timber is operating on a sustained-yield management plan, he may have to salvage large volumes of killed

timber to maintain the annual allowable cut. The timber owner also must consider the danger of increased damage by insects in fire-injured trees or green trees. He must consider the fire hazard to adjoining forests and to new tree growth in the burned area when fire-killed timber is left unsalvaged.

Management objectives may dictate either the removal or the leaving of fire-killed timber, regardless of whether the salvage operation in itself is profitable. Fire-killed trees in a watershed may have to be removed to permit replanting for prevention of runoff or soil erosion, or reforestation to assure maximum timber production. On the other hand, the soil and slope in a burned watershed may be such that logging is not feasible if erosion is to be prevented.

SUMMARY AND CONCLUSIONS

The rate and agents of deterioration in fire-killed forest trees were studied in 523 trees in 16 burns distributed throughout the main commercial timber range in California. The species studied were ponderosa, Jeffrey, and sugar pines, Douglas-fir, and white fir. The burns varied from 0 to 17 years of age.

Fungi and insects are the principal agents causing deterioration. These two agents are so intimately associated that their effects are best considered in combination rather than separately. Two degrees of deterioration were recognized: limited and general. Limited deterioration, caused principally by the blue-staining fungi, causes degrade of lumber manufactured from the sapwood. General deterioration, caused principally by wood-decaying fungi and wood-boring insects, makes the wood undesirable for lumber even of low grade.

Three species of fungi cause most of the decay of fire-killed trees. Listed in descending order of importance they are: *Fomes pinicola*, *Polyporus voltatus*, and *P. abietinus*. The latter two ordinarily are confined to the sapwood, although *P. abietinus* at times also decays the heartwood of white fir trees. *F. pinicola* is the principal decayer of both sapwood and heartwood. Several other species of fungi cause minor amounts of decay in the wood of fire-killed trees. Wood-boring insects advance at rates similar to those of the decay fungi and help to deteriorate fire-killed trees; however, their galleries seldom become abundant enough to cause cull of the wood before fungi render it useless for lumber. Checking due to weather at times causes part of the deterioration. Weather check is especially important on dry sites at high elevations.

Deterioration in fire-killed trees starts just under the bark and progresses rather uniformly toward the pith. There is little loss from deterioration in the first year after a tree is killed by fire. Some degrade, caused mostly by blue stain, may be encountered toward the end of the first year under average conditions. During the second year, blue stain and incipient decay occur in much of the sapwood, and by the end of the third year practically no sapwood is salvable. After the third year, only the larger trees contain sufficient sound wood to make salvage economically feasible.

Although white fir sapwood does not ordinarily stain severely, it often decays extensively by the end of the second year. Since the

sapwood of this species is exceptionally thick, only large logs may be merchantable after the second year. The heartwood also decays rapidly, so little white fir may be salvaged after the third or fourth year.

Ponderosa and Jeffrey pines have thick sapwood, but general deterioration is comparatively slow in the sapwood, so that, except for some degrade from blue stain, there is practically no loss until after the first year. Even at the end of the third year some sapwood may be salvaged. However, since the sapwood usually makes up more than half the volume in these pines, few logs may be salvaged after about 5 years.

Sugar pine sapwood is somewhat thinner than that of the other pines, but it blue-stains rapidly. By the end of the second year the sapwood is about 75 percent deteriorated. Since the heartwood is comparatively resistant, large logs may be salvaged for 10 years or more after a fire.

Douglas-fir sapwood is thin and deteriorates beyond use for lumber in 3 years. However, it does not blue-stain severely, so most loss in the sapwood occurs from decay in the second year. The heartwood decays slowly in old trees, so that large logs may be salvaged 15 to 20 years after the death of the trees.

Other than the species and size of trees, environment probably influences the rate of deterioration more than anything else. Climate seems to be the most important environmental factor, and, in California, moisture is usually the most critical requirement for decay and insect activity in the dead trees. On extremely dry sites the trees may become so dry that activity of fungi and insects is arrested except near the ground where moisture and other conditions are most favorable for their growth and development. On exceptionally wet sites, the most favorable conditions will be in the tops of the trees. The drier the habitat, the lower in the bole are growing conditions favorable for fungi; on extremely dry sites the most rapid deterioration is at the ground line.

A supplemental study of 55 trees (representing all species studied) in 3 burns showed that trees with their foliage burned off remained wet longer than trees with attached dead foliage, but deterioration was retarded in the wet trees only on the wetter sites. It was accelerated in the wet trees on dry sites.

Heartwood deterioration was faster in trees with wide growth rings than in those with comparatively narrow growth rings. This was especially noticeable in the species with the more durable heartwood.

Younger trees deteriorated more rapidly than older trees when other conditions were the same.

To plan the salvage of fire-killed trees, timber owners or operators must consider, besides the rate of deterioration, the physical factors of the job, timber values and operating costs, and whether leaving killed timber or logging it will be better for the burned area and surrounding forests.

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